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Analysis of Alternatives in System Capability Satisficing for Effective Acquisition

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Abstract

Under the direction of the Principal Investigators and support from the Acquisition Research Program and government and industry partnerships, the Systems Development & Maturity Laboratory (SysDML) at Stevens Institute of Technology has successfully developed, tested, and implemented a system maturity measure (i.e., System Readiness Level) and supporting optimization models for inclusion in a System Earned Readiness Management methodology. Currently the SysDML is integrating these previous developments into tools to quantify maturity in multi-function, multi-capability (MFMC) systems. Given that the trend is for systems to provide MFMC, it has become challenging for managers to properly assess their development and acquisition to ensure the achievement of critical capabilities and functions. Moreover, such a challenge is compounded when the systems are not only comprised of MFMC but have multiple or competing technology and integration alternatives. This challenge, then, raises a fundamental question: **How do we effectively assess the maturity of a system for acquisition when considering technology and integration alternatives or trade-offs in a MFMC system?** This research intends to answer this question and provide results that can be used to evaluate systems development maturity, track progress, identify component criticality, and form corresponding strategies for further development and trade-offs in technology and integration alternatives.

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14. ABSTRACT

Under the direction of the Principal Investigators and support from the Acquisition Research Program and government and industry partnerships, the Systems Development & Maturity Laboratory (SysDML) at Stevens Institute of Technology has successfully developed, tested, and implemented a system maturity measure (i.e., System Readiness Level) and supporting optimization models for inclusion in a System Earned Readiness Management methodology. Currently the SysDML is integrating these previous developments into tools to quantify maturity in multi‐function, multi‐capability (MFMC) systems. Given that the trend is for systems to provide MFMC, it has become challenging for managers to properly assess their development and acquisition to ensure the achievement of critical capabilities and functions. Moreover, such a challenge is compounded when the systems are not only comprised of MFMC but have multiple or competing technology and integration alternatives. This challenge, then, raises a fundamental question: How do we effectively assess the maturity of a system for acquisition when considering technology and integration alternatives or trade‐offs in a MFMC system? This research intends to answer this question and provide results that can be used to evaluate systems development maturity track progress, identify component criticality, and form corresponding strategies for further development and trade‐offs in technology and integration alternatives.

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1. Introduction

Under the direction of the Principal Investigators (PIs) and with support from the Naval Postgraduate School (NPS) Acquisition Research Program and government and industry partnerships, the Systems Development and Maturity Laboratory (SysDML) at Stevens Institute of Technology has successfully done the following:

a) Developed a methodology for determining a system's development/acquisition maturity (i.e., System Readiness Level [SRL]; Sauser et al., 2008; Sauser & Ramirez-Marquez, 2009) (NPS BAA 07-002, 2007);

b) Formulated two optimization models for allocating resources so as to optimize cost, schedule, and maturity performance (i.e., SRL_{max} and $SCOD_{min}$; Sauser & Ramirez-Marquez, 2009; Sauser & Ramirez-Marquez, 2009; Magnaye, Sauser et al., 2010) (NPS BAA 07-002, 2007);

c) Defined a methodology that combines previous Items a and b into an approach called Systems Earned Readiness Management (SERM; Magnaye, Sauser, & Ramirez-Marquez, 2009; Sauser & Ramirez-Marquez, 2009; Magnaye et al., 2010) (NPS BAA 08-004, 2008); and

d) Developing models to determine which components (i.e., the technologies are integrations the system is build off) are sufficient, critical, or important to achieve a level of system maturity for the intended functionalities and capabilities that can satisfy warfighters' needs (Tan et al., 2010a; Tan et al., 2010b) (NPS BAA 09-002, 2009).

It is important to note that throughout these research efforts, the SysDML has maintained an evolutionary development approach through which we have worked closely with industry and government to refine and implement our research in order to ensure its relevance and rigor (see Exhibit 1).

The research results described in this report address some recurring issues that were revealed through conversations with our industry and government research partners. In essence, we are answering the following question: What are the effects of necessary trade-offs in functionality, capability, cost, schedule, and maturity that will allow the acquisition of a system that can still satisfy warfighter needs? The objective is to be able to do the following:

1) Identify the critical components to system maturity; that is, which components (i.e., technologies or integrations) have the greatest impact on system maturity;
2) Prioritize component development based on constrained resource availability; and
3) Balance between system capabilities/functions with a given developmental budget.

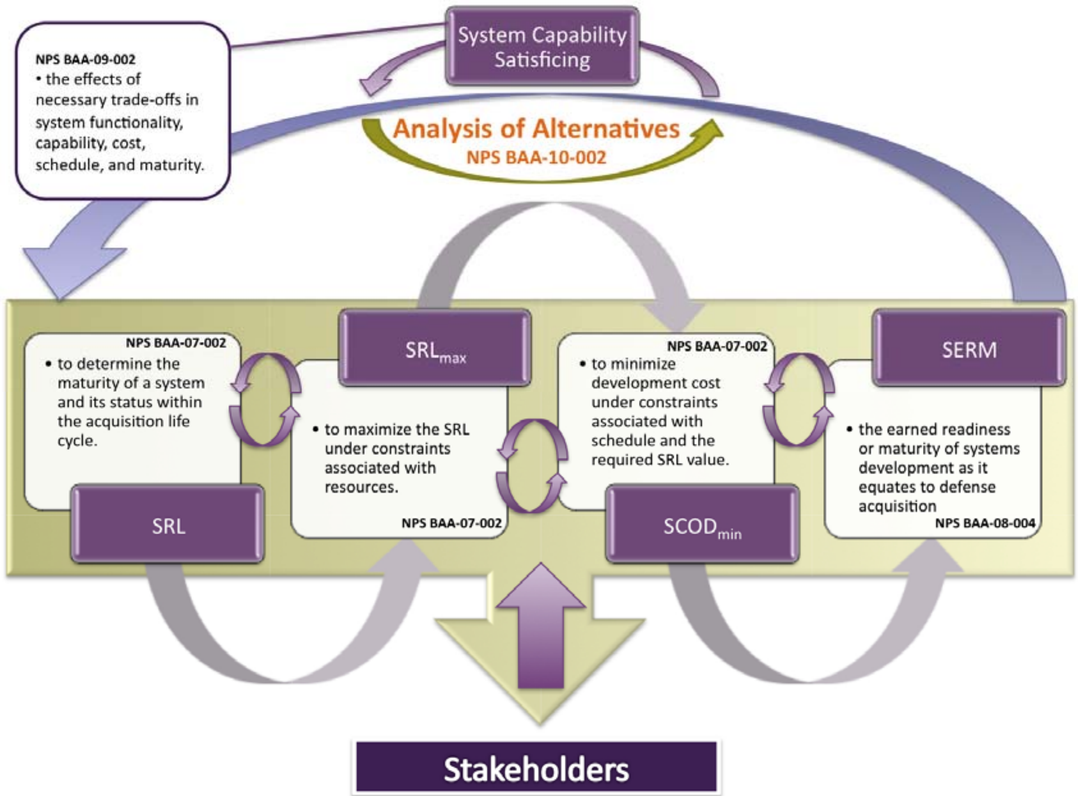

Exhibit 1. Evolutionary Development Plan

While the previous research is absolutely necessary and relevant for a better understanding of how to achieve effective maturity, capability, and functionality of a system for acquisition, it still does not address a fundamental activity in the development of system solutions that this research addressed. To clarify, in any systems solution, a systems engineer or acquisition manager must make critical, necessary, and sufficient trade-offs with respect to technologies and integrations based on Analysis of Alternatives (AoA), and these trade-offs come at a cost/benefit to the functionality and capability of the system and its existing architecture. There is increasing development and acquisition of systems that are built upon open and flexible platform designs that can accommodate multiple functions and capabilities as well as the ability to adopt future mission packages (e.g., modularity, system of systems). With such a trend, decisions to trade off among multiple alternatives that enable necessary functions and capabilities will be unavoidable. Therefore, this research is timely and critical in that it intends to build upon the current research funded by the Acquisition Research Program on System Capability Satisficing to develop a methodology for an AoA (or trade-off) for technology and integration component adoption, which impacts the system maturity, functionality, and capability (see the orange arrow in Exhibit 1).

2. Purpose and Focus of Research

Over the past four years, the SRL scale and supporting methods have undergone continuous development and have been accepted as a valid metric to measure the readiness of a system throughout its development life cycle (implementations of this metric have been performed by U.S. Navy–PMS420, U.S. Army–ARDEC, Lockheed Martin, and Northrop Grumman). However, to date, this scale has focused on the management of systems intended to perform a single function. Today, even the most basic weapons such as assault rifles have become multi-functional. As such, during the development process, these systems may be called upon to deliver some of their capabilities even as the development of others is still several phases behind. Often, this requires an AoA among technology choices and architectures to take advantage of those that are already mature, though not originally intended for use in the development of the desired function. This, in turn, requires a thorough understanding of the technical aspects of the components but, more significantly, the relative importance of each choice on the readiness of the system vis-à-vis its desired capability.

One of the first researchers to describe this necessity for the management of systems development was Birnbaum (1969), who introduced a quantitative definition of component importance. Since then, the area of component Importance Measures (IM) has received significant attention, and its utility has gained more and more recognition. For example, Hwang (2001) specified that an importance index is for the measurement of the relative importance of a component with respect to other components in a system, and thus, it can be used to rank the contributions of components or basic events to the system's performance (Baraldi, Zio, & Compare, 2009). Thus, by their definition, IM can quantify the criticality of a particular component within a system, be used as a tool for evaluating and ranking the impact of individual components, determine the most important component with respect to the overall system performance, identify system weaknesses, and prioritize system performance improvement activities (Ramirez-Marquez and Coit, 2005, 2007). Zio, Marella, and Podofillini (2007) further emphasize the great practical aid provided by IMs in that they allow system designers and managers to track system bottlenecks and also provide guidelines for effective actions when determining system improvements. This body of knowledge in IM research has added significant value to our understanding of the non-linearity in the importance of technologies and integrations within a system, but it does not consider the technology and integration alternatives (or trade-offs) and their importance to the decisions made in the development and acquisition of a systems solution.

In practice, a system evolves with time from a single capability or a specific function to a more complicated one that affords multiple functions, and to ensure the operational performance of a function by having several backup capabilities. Kim et al. (2009) specified that a technical system usually comprises a number of subsystems and components that are interconnected in such a way that the system is able to perform multiple required functions. Moreover, in order to ensure the success of the development or acquisition of a system, even for a specific function, it is common to have one or several backup capabilities. These systems are often required to be open to further integration of other mission packages in order to satisfy future requirements for a yet-to-be-defined service (GAO, 2008). In addition, in the evolution of systems development, the advancement of technology options is progressing faster than the systems themselves. In this process, the following questions may arise: Will a new, more functional system or technology supersede the old? Has the system or technology become inadequate due to changes in other systems or technologies? Is it more effective to invest in the development of a new system or technology? Has the system or technology lifetime been shortened by recent developments? What is a robust methodology that can effectively and efficiently analyze, compare, and trade off technology alternatives?

With an ever-increasing complexity of the systems that are being developed and realized, multiple functions and capabilities are common to the development of most systems, which raises the need to balance development objectives when facing multiple component alternatives. As a result, managers require metrics that enable the assessment of multi-function, multi-capability (MFMC) system developmental maturity to manage the potential risks posed by the previous questions (Volkert, 2009).

For example, Forbes, Volkert, Gentile, and Michaud (2009) have described a system with six capabilities that are realized by six threads of components. The architecture of this system is represented in Exhibit 2. As described in their paper, this system had undergone a system maturity assessment with summary charts also depicted in Exhibit 2. The initial system architecture represented in Exhibit 2(a) resulted in an assessment with an overall SRL of 0.60 (see MP SRL in the upper right box of the diagram); the identification of an insufficiently mature technology and supporting integrations (circled in the diagram); and analysis of the technology-integration maturity of all the system components (a horizontal line at the bottom of the diagram). An alternative systems solution based on a trade-off (see Exhibit 2[b]), considered replacing a single technology (i.e., MVCS) with another two technologies (i.e., DLS OB; DLS RMMV). This alternative does not significantly improve the overall SRL value (an increase of only 0.04), but it does improve the technology-integration maturity of all the lagging system components (a horizontal line at the bottom of the diagram). While this analysis may seem sufficient in increasing systems maturity toward an effective acquisition decision, it does not consider many of the IMs related to an AoA and their influence on the system's current or future maturity. Thus, a decision made purely on an increase in maturity may be insufficient. This described research intends to address this concern by enhancing the SRL approach to take into account the multiple system functions and capabilities, which allows for the opportunity to better understand an analysis of alternatives in technologies and integrations to more effectively manage system maturity and acquisition.

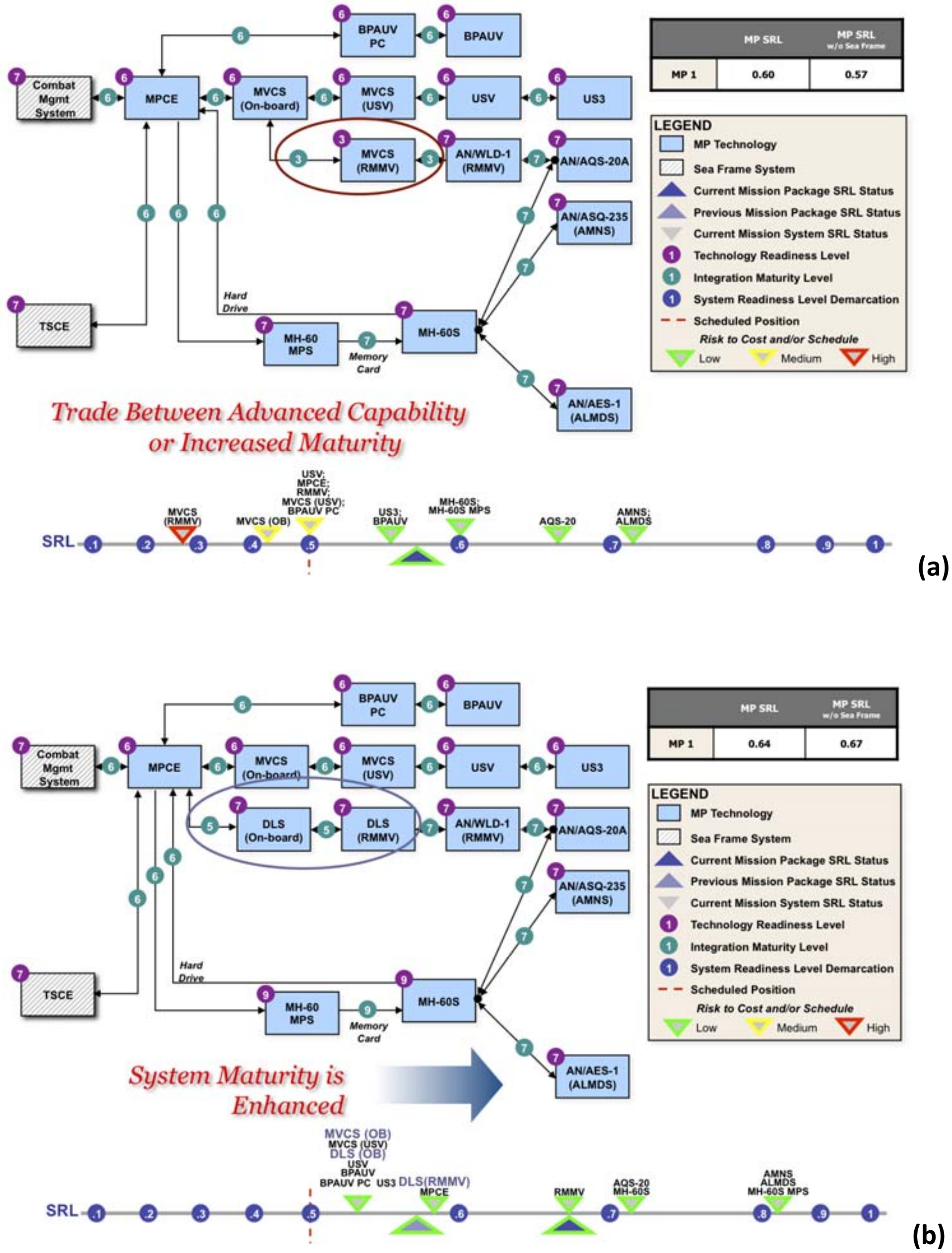

Exhibit 2. Technology/Integration Trade-Off Analysis

3. Research Approach

In the domain of system architecture and AoA, identifying, prioritizing, and ranking components with respect to their impact on the system is key to understanding the importance of any one component to another and is notable for suggesting trade-offs among key parameters during their development and acquisition. This research contributes to the body of knowledge by bridging the gap in the analysis of traditional system architectures with system maturity assessment. It is expected that such analysis will assist in the establishment of system development and acquisition strategies from the quantification of the relationship between component maturity and system maturity and distinguishing the importance of different components for making informed decisions when deciding to trade off technology and integration alternatives without rushing to judgment on a preferred systems solution or architecture.

In an AoA, the main objective is to execute an extensive analysis that would result in a preferred system architecture. Key in the execution of this analysis will be the IMs that describe the most important components for the performance of the system. What we are proposing is a variation on a traditional AoA in that the key performance indicator would be the maturity of the technologies and integrations supporting the systems' functionalities and capabilities and the yet-to-be-defined IMs. To enable the AoA by taking into consideration the notions of function and capability in a system, this research proposes a hierarchical SRL (see Exhibit 3), where the SRL is defined at the following three different levels:

1) *Capability-based SRL*

SRL_C_{fk} denotes the SRL for capability C_{fk}. It is defined as the average of all the normalized Integrated-Technology Readiness Level (ITRL) values, which is given by

$$SRL\_C_{fk} = \frac{ITRL\_C_{fk(1)} + ITRL\_C_{fk(2)} + ... + ITRL\_C_{fk(n_{fk})}}{n_{fk}} = \frac{\sum_{i=1}^{n_{fk}} ITRL\_C_{fk(i)}}{n_{fk}}$$

2) *Function-based SRL*

SRL_F_f is the *SRL* for function F_f. Although there are multiple capabilities to ensure the same function, the maximum of these Capability-based SRLs represents the readiness of that function and is defined as

$$SRL\_F_f = Max(SRL\_C_{fk}), \;\; k = 1,2,...,K_f$$

SRL_F matrix includes all the Function-based SRLs and is denoted by

$$\boldsymbol{SRL\_F} = \begin{bmatrix} SRL\_F_1 \\ SRL\_F_2 \\ ... \\ SRL\_F_r \end{bmatrix} \qquad (10)$$

3) *Composite SRL*

Composite SRL for the whole system is the average of all Functionality SRLs and is defined as

$$Composite \;\; SRL = \frac{(\sum_{k=1}^{K_1} SRL\_F_{1k}) + (\sum_{k=1}^{K_2} SRL\_F_{2k}) + ... + (\sum_{k=1}^{K_r} SRL\_F_{rk})}{K_1 + K_2 + ... + K_r} = \frac{\sum_{f=1}^{r}\sum_{k=1}^{K_f} SRL\_F_{fk}}{\sum_{f=1}^{r} K_f}$$

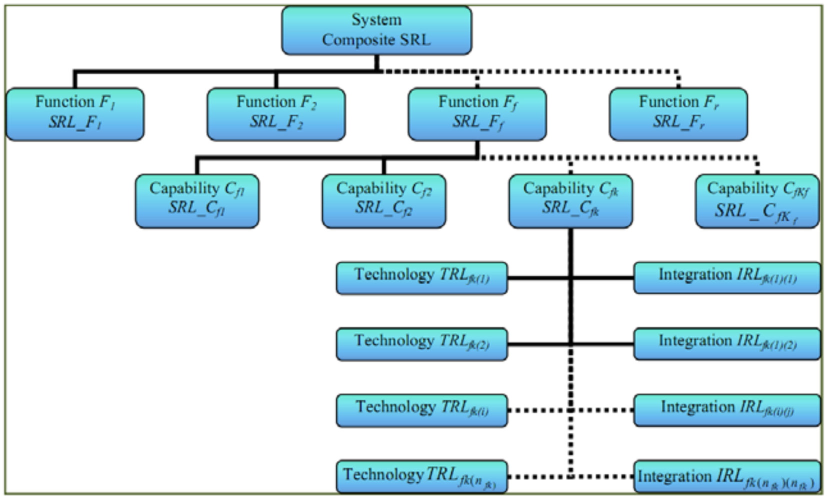

Exhibit 3. SRL Hierarchy

The capability-based SRL calculates the SRL for a particular capability thread that includes a set of components to enable an intended capability. Based on the calculation of SRL_C's, the function-based SRL addresses the SRL for a specific function that encompasses one or several capability threads. The Composite SRL indicates the SRL for the whole system, which includes multiple functions with multiple capabilities. This hierarchical assessment is then used as a baseline for the AoA related to trade-offs in technology and integration options. Exhibit 4 represents a typical process of an AoA. The phases identified in Exhibit 4 are described in the next section.

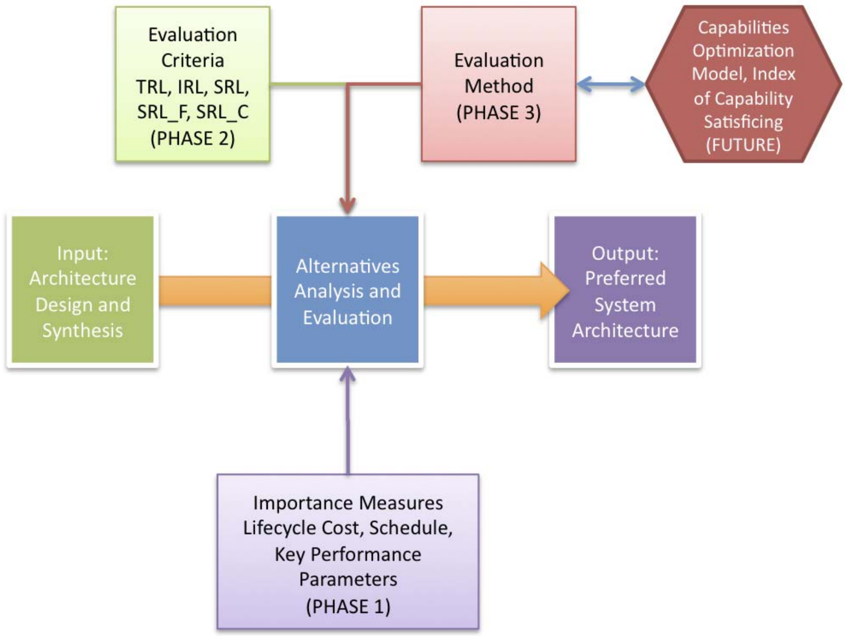

Exhibit 4. Alternative Analysis

This research was executed in the following three phases:

Phase 1—Identify MFMC AoA Metrics: This phase will identify key metrics for the development of the MFMC AoA IMs as it relates to a trade-off analysis. What we have proposed are preliminary representations, which need further work and understanding on how they relate to architectural variants in functionality and capability for acquisition.

Phase 2—Verification of the MFMC AoA Metrics and Models with Systems: We applied these models to real systems from Lockheed Martin (Morristown, NJ; Orlando, FL), Northrop Grumman Integrated Systems, and the U.S. Army Armament Research, Development and Engineering Center (ARDEC). This application resulted in refinement and adjustment to the quantitative correlations of the models based on Phases 1 and 2.

Phase 3—Development of a Methodology: We documented a process methodology for the use of the MFMC AoA models so further work can be carried out with validation of the models with those stakeholders identified in Phase 2. We also explored some preliminary optimization models and capability satisficing indexes for development of a more robust acquisition decision approach.

4. Illustrative Example of Implementation of Results

The MFMC AoA methodology is demonstrated with a system that was previously discussed by Forbes, Volkert, Gentile, and Michaud (2009) and shown in Exhibit 2. There are basically two functions—Mine Detection and Mine Neutralization—to be performed by this system. There are six capabilities that are realized by six threads of components, as listed in Exhibit 5: four capabilities in the first function (shaded green in the exhibit) and two capabilities in the second function (shaded yellow in the exhibit). These capabilities are 1) Bottom Mapping & Change Detection; 2) Shallow & Littoral Water Mine Detection; 3)

Bottom & Volume Mine Detection–I; 4) Bottom & Volume Mine Detection–II; 5) Contact Mine Neutralization; and 6) Influence Mine Neutralization.

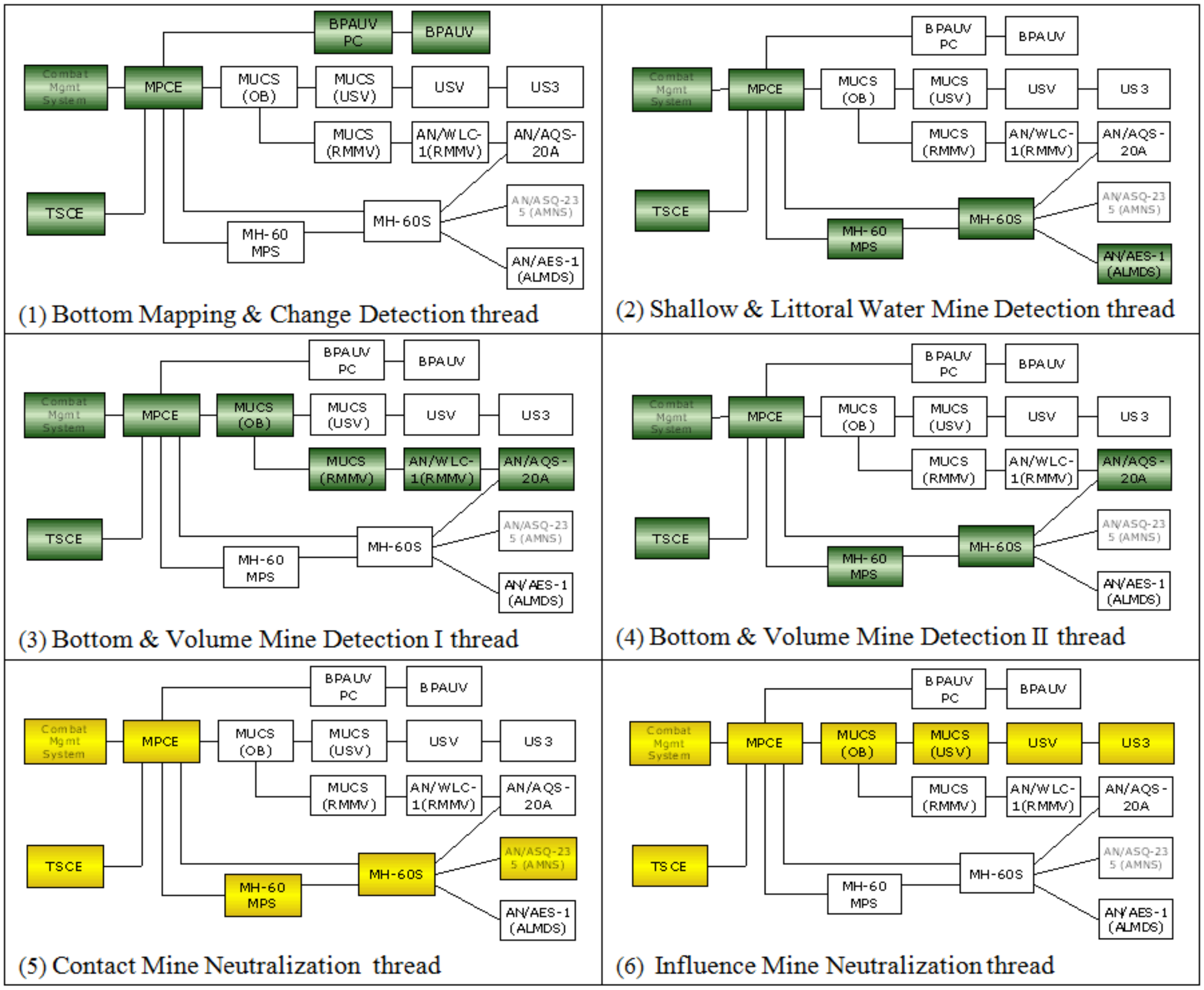

Exhibit 5. A MFMC System with Two Functions and Six Capabilities

Exhibit 6 shows the results from using a tool that utilizes the proposed SRL hierarchy to assess system maturity. The left side of the figure displays the new hierarchy for the estimates of system development maturity at different levels: ITRL, capability, function, and system levels. It adds two layers (capability and function) to the original SRL definition to provide more accurate assessment and more insights for systems engineering managers to track the progression on life cycle of the systems' development. In addition, three other user inputs are added to the assessment:

- Expected SRL: this is the SRL value that is expected at the time of the assessment or a projected time in the life cycle.
- Red Bar: this is the lower threshold value of the SRL. If an ITRL, capability, or function assessment falls below this level, it is indicated in red.

- Yellow Bar: this is the upper threshold value of the SRL. If an ITRL, capability, or function assessment falls above this level, it is indicated in yellow.

Any value for the ITRL, capability, or function assessment that falls within the thresholds is indicated in green. The development of this illustrative system is mapped to the DoD Acquisition Life Cycle to determine the development progression. As shown in Exhibit 6, with a 10% margin of the expected SRL 0.53 as the risk thresholds, we can observe the following:

1) The system level SRL indicates that the whole system is progressing on schedule with an SRL value of 0.51, compared to the expected value on this particular assessment date.
2) Although the development of Function 1 is ahead of schedule with an SRL value of 0.59, there is variability in the development of the individual capabilities that make up Function 1.
3) The ITRLs in Exhibit 6 are for the selected Capability 2.2, which is within the target threshold, but ITRLs 2 and 4 indicate a risk in falling behind, though the rest the ITRLs in this capability are being developed as planned.

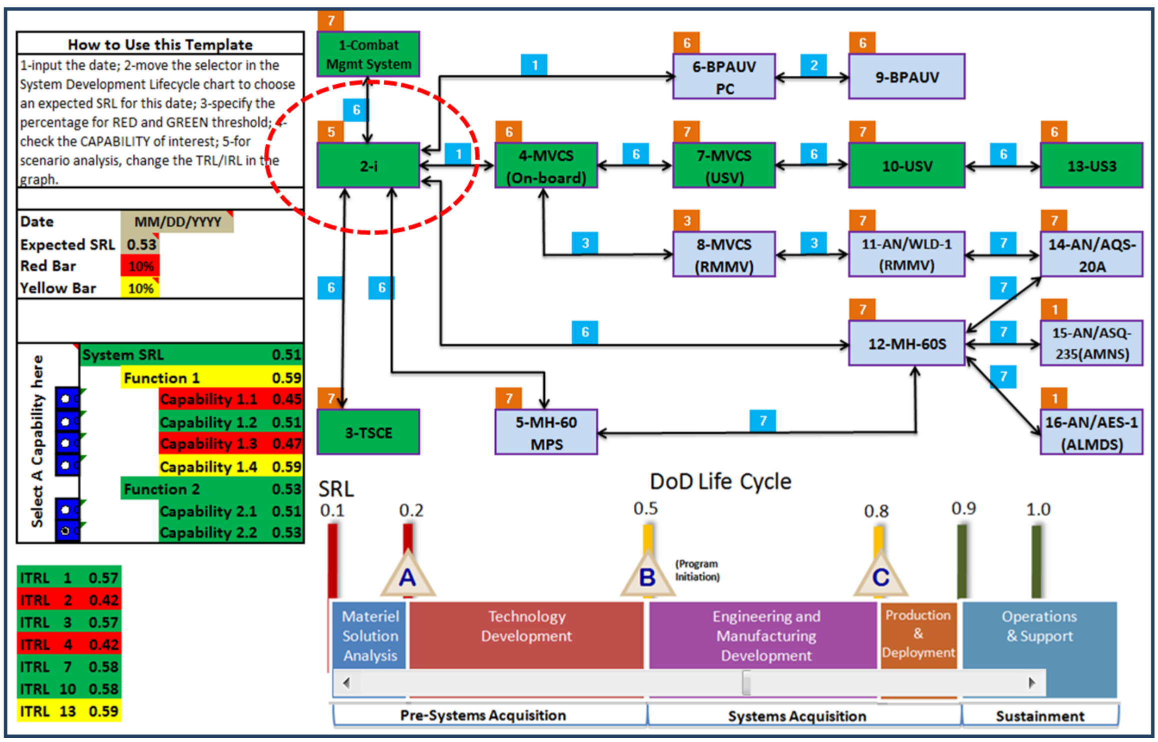

Exhibit 6. Alternative i

The use of the enhanced SRL hierarchy and the employed assessment tool provides developers and managers with a holistic picture to investigate the system development and with the ability to easily identify system development weaknesses as indicated by variations around a threshold. This example also manifests the multi-dimensional nature of system maturity assessment, which should be examined at different levels within the same system architecture for which an assessment using a single number would have overlooked.

This tool and approach facilitates the aforementioned AoA to examine multiple alternatives to get the best possible solution to satisfy customer requirements. Exhibit 7 shows the assessment of a different alternative to Exhibit 6, only replacing Technology 2–i with 2–ii that is assumed to provide the same functionality (see the circled technology). While more mature in its TRL and IRLs with Technologies 4 and 6, the inclusion of Technology 2–ii leverages the progression of Capabilities 1.1 and 1.3, which were previously identified to be lagging in Alternative–i (Exhibit 6). Meanwhile, at the ITRL level for Capability 2.2, all ITRLs are balanced to be either on or ahead of development schedule. Compared with Alternative–i, Alternative–ii (Exhibit 7) significantly outperforms in terms of meeting and balancing development maturity and potentially mitigates some of the risk of meeting customer expectations. Therefore, based on the analysis of these two alternatives, the second option with Technology 2–ii is the preferred alternative.

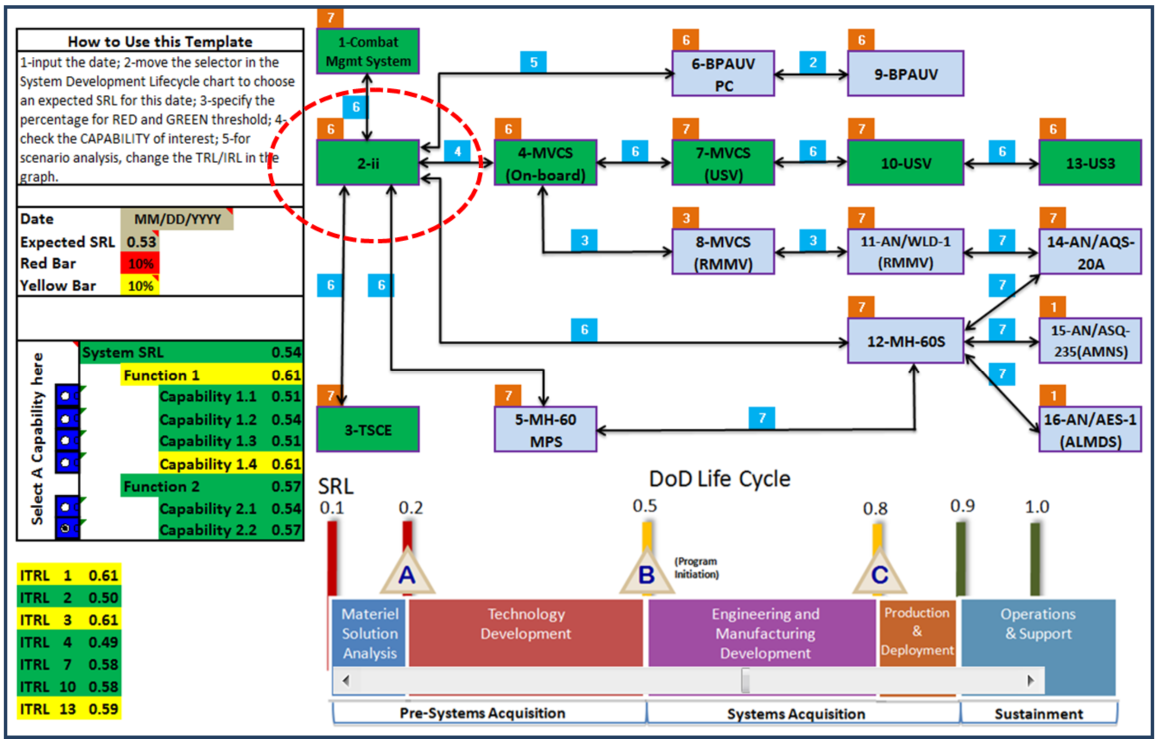

Exhibit 7. Alternative ii

It should be noted that although it seems quite simple and intuitive from the comparison of these two alternatives, this example is only for illustration purposes. In practice, the method presented in this paper will have more value when utilized on more complicated architectures that involve a number of different components (technologies and integrations) and the interplay among them. In such situations, it will not be straightforward and intuitive like this one and can hardly be cognitively comprehended, where the use of such a tool and multi-layer hierarchy is very necessary for trade-offs in MFMC systems acquisition.

5. Managerial Implications and Future Research

In order to address a challenging system acquisition problem of effectively assessing the development maturity with the consideration of technology and integration alternatives in MFMC systems, this research proposes an enhanced SRL hierarchy and an AoA methodology. With the use of a tool, the proposed methodology was demonstrated with an illustrative example. As evidenced, this methodology moves us closer to facilitating more informed maturity assessments for MFMC systems development and AoA that can assist the acquisition of DoD weapon systems.

Previous efforts funded by the Acquisition Research Program addressed some recurring issues that were revealed through conversations with our industry and government research partners. In essence, we were answering the following question: What are the effects of necessary trade-offs in functionality, capability, cost, schedule, and maturity that will allow the acquisition of a system that can still satisfy warfighters' needs? Our research funded via the Acquisition Research Program helped to answer the question by 1) identifying the critical components to system maturity; that is, which components (i.e., technologies or integrations) have the greatest impact on system maturity; 2) prioritizing component development based on constrained resource availability; and 3) balancing between system capabilities/functions with a given developmental budget.

While the previous research has proven necessary and relevant for a better understanding of how to achieve effective maturity, capability, and functionality of a system for acquisition, it does not address a fundamental activity in the development of system solutions that this research introduces. To clarify, in any systems solution, a systems engineer or acquisition manager must make critical, necessary, and sufficient trade-offs with respect to technologies and integrations based on AoA, and these trade-offs come at a cost/benefit to the functionality and capability of the system and its existing architecture. There is increasing development and acquisition of systems that are built upon open and flexible platform designs that can accommodate multiple functions and capabilities as well as the ability for adopting future mission packages (e.g., modularity, system of systems). With such a trend, decisions to trade off among multiple alternatives that enable necessary functions and capabilities will be unavoidable.

6. Knowledge Transfer to Industry/Government

We have continued to maintain a rich knowledge transfer relationship with industry and government. The following are some examples:

- U.S. Army Armament Research Development and Engineering Center (ARDEC): The ARDEC has implemented the SRL method on an innovative lightweight vehicle program that has allowed them to assess current development risks as well as create development plans for program reviews.
- Lockheed Martin (LMCO): LMCO has piloted the SRL on four projects. Based on its success and lessons learned from the application, they are now using it on a major weapons program. In addition, they used internal corporate funds to create an SRL software tool that has allowed them to calculate an SRL and evaluate development risks for program reviews.
- Northrop Grumman (NGC): NGC has continued to use SRL in support of their efforts with PMS420 and incorporated the methods into their own internal tool for program assessment.

7. Project Accomplishments

7.1. Publications

7.1.1. Journal

Concho, L., Ramirez-Marquez, J., Hearld, T., & Sauser, B. (2011). Functionally equivalent COTS for optimal component substitution within system evolution planning. *Technology Analysis & Strategic Management, 23*(5), 509–526.

7.1.2. Conference Proceedings

Sauser, B., Tan, W., & Ramirez-Marquez, J. (2011, May 11–13). Analysis of alternatives in system capability satisficing for effective acquisition. In *Proceedings of the Eighth Annual Acquisition Research Symposium.* Monterey, CA: Naval Postgraduate School.

7.1.3. Working Papers

Sarfaraz, M., & Sauser, B. (2011). Improving system maturity assessment using system engineering architectures.

Magnaye, R., Sauser, B., & Pantanakul, P. (2011). Earned readiness management for scheduling, monitoring and evaluating the development of systems.

Sauser, B. J., Magnaye, R., Tan, W., Ramirez-Marquez, J., & Sauser, B. W. (2011). Optimization of system maturity and equivalent system mass for space systems engineering management.

Tan, W., Sauser, B., Ramirez-Marquez, J., & Magnaye, R. (2011). Multi-objective optimization in multifunction multicapability systems development planning.

7.2. Presentations

Sauser, B., & Ramirez-Marquez, J. (2010, May 19). System capability satisficing in defense acquisition via element importance measures. Paper presented at the *Seventh Annual Acquisition Research Symposium*. Monterey, CA: Naval Postgraduate School.

8. Other Related Activities

8.1. Website

From the birth of this research, we have believed in an open academic model of sharing our research outcomes in the broadest sense possible. Thus, we have sustained our website, http://www.SysDML.com, for the distribution of our research results. At this website, you will find the following pages: Research Overview; Publications; Research Projects; Tools; and Who We Are.

8.2. Student Research Supported/Supervised

Our funding from the Naval Postgraduate School has afforded us the privilege to support one PhD student to assist in the execution of this research. It has also allowed us the ability to attract graduate students to pursue related and supportive research. These students are the following:

Ivonne Donate. PhD student (currently supported by the Department of Defense). *Evolutionary lifecycle assessment for disruptive technology integration*.

Ryan Gove. PhD student (currently supported by Lockheed Martin). *Model based systems engineering for effective system maturity assessment*.

Samuel Russell. PhD student (currently supported by NASA). *The thermodynamics of system development: A mechanistic approach to system maturity assessment*.

Matin Sarfaraz. PhD student (currently supported by the Innovation and Entrepreneurship Graduate Fellowship). *Systems engineering artifact correlation to systems maturity assessment*.

Weiping Tan. PhD student (currently supported by NPS). *Methodologies for component importance analysis in multi-function, multi-capability system developmental maturity assessment*.

Joseph Uzdzinski (currently supported by Lockheed Martin). System maturity assessment for dynamic interoperability in complex systems.

Graduates

Romulo Magnaye. (May 2011). *Using a system maturity scale to monitor and evaluate the development of complex systems*. PhD in Engineering Management. Currently an Assistant Professor at Ramapo College.

8.3. Student Projects Supervised

Within the School of Systems and Enterprises at Stevens Institute of Technology, students are encouraged to complete a 3-credit special problems project as part of their course requirements. Because of the success of this research, we have been able to attract a number of students to pursue projects related to SRL and related topics. Here is a list of these students and projects:

Legath, M. (2011). *System lifecycles and the unpredictable nature from conception to sustainment*. MS Special Problems in Systems Engineering.

Tay, K-H. (2011). *Addressing obsolescence in the system readiness level (SRL) scale to support major defense acquisition decisions*. MS Special Problems in Systems Engineering.

9. Bibliography

Baraldi, P., Zio, E., & Compare, M. (2009). A method for ranking components importance in presence of epistemic uncertainties. *Journal of Loss Prevention in the Process Industries*, *22*(5), 582–592. doi:10.1016/j.jlp.2009.02.013

Birnbaum, Z. W. (1968). *On the importance of different components in a multicomponent system* (Technical Report No. 54). Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/670563.pdf

Forbes, E., Volkert, R., Gentile, P., & Michaud, K. (2009). Implementation of a methodology supporting a comprehensive system-of-systems maturity analysis for use by the Littoral Combat Ship mission module program. In *Proceedings of the Sixth Annual Acquisition Research Symposium*. Monterey, CA: Naval Postgraduate School.

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Hwang, F. K. (2001). A new index of component importance. *Operations Research Letters*, *28*(2), 75–79.

Kim, D. J., Kim, H. C. et al. (2009). Evaluation of structural importance based on minimal cut set theory. *Transactions of the Korean Institute of Electrical Engineers, 58*(3 P), 27–32.

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